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INVESTIGATION TO ELIMINATE THE DETRIMENTAL EFFECT OF DUST-SUPPRESSING-WETTING AGENTS ON FLOTATION RESULTS (OPEMISKA COPPER ORE)

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INVESTIGATION TO ELIMINATE THE DETRIMENTAL EFFECT OF DUST-SUPPRESSING-WETTING AGENTS ON FLOTATION RESULTS (OPEMISKA COPPER ORE)

by

M.A. Cristovici* and T. Gilmour**

ABSTRACT

Surfactants selected as potential dust suppressors proved to have a negative effect on flotation results of the ore contaminated with such reagents. An investigation carried out to eliminate this drawback succeeded in developing a technique by which the detrimental influence of the surfactants was annihilated. The method, which has been tested on Opemiska copper ore (collective flotation), consisted of adsorbing the surfactants on activated carbon and separating the carbon from the ore prior to flotation. The amount of carbon addition and contact time depended on the quantity and surfactant concentration of the solution sprayed on the ore.

The investigation continues to adapt the surfactant-adsorption technique to more complex mineralization.

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ÉTUDE VISANT À ÉLIMINER L'EFFET NÉGATIF DES AGENTS DEPRIMANT LA POUSSIÈRE SUR LES RÉSULTATS DE LA FLOTTATION (MINERAI DE CUIVRE D'OPEMISKA)

par

M.A. Cristovici* et T. Gilmour**

RÉSUMÉ

On a trouvé que les agents tensio-actifs choisis pour la suppression de la poussière minerale avaient un effet négatif sur les résultats de la flottation d'un minerai contaminé par de tels réactifs. L'étude que l'on a effectué pour éliminer cet inconvénient a permis de mettre au point une technique à l'aide de laquelle l'influence négative des agents tensio-actifs a été annihilée. La méthode, qui a été expérimentée sur un minerai de cuivre d'Opemiska (flottation collective), consistait à adsorber les agents tensio-actifs sur du charbon activé et à séparer le charbon du minerai avant la flottation. La quantité de charbon ajoutée et le temps de contact utilisé dépendaient de la quantité et de la concentration de solution des agents tensio-actifs arrosée sur le minerai.

On continue les études pour adapter la méthode d'adsorption des agents tensio-actifs déprimant la poussière minerale à des minéralisations plus complexes.

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INTRODUCTION

Surfactants supplied by various manufacturers of chemicals were investigated for their properties and ability to suppress sulphide ore dust. The results of the first part of this investigation were published in 1983 (Ref. 1).

A number of surfactants were selected as potential dust suppressors but the search for finding more adequate and cheaper wetting agents continued. In the second part of the study more surfactants were examined and selected to be further investigated as dust suppressors.

However, since the use of wetting agents to combat dust will result in a surfactants-contaminated ore, it was imperative to determine if the presence of wetting agents would adversely affect the efficiency of minerals extraction during subsequent processing.

Flotation is the method of extraction used almost exclusively to process base metal sulphide ores, which are the ones requiring wetting agents for dust suppression. Therefore, the most appropriate way to assess possible interference of the surfactants in the mineral extraction process was to investigate the influence of the wetting agents on flotation results.

Two types of base metal ore were studied to reveal the surfactant's influence: low sulphide content ore, ore with one recoverable mineral, represented by Opemiska copper ore, and medium-high sulphide content, polyminerals ore represented by Kidd Creek copper-zinc ore.

Comparative flotation tests, with and without surfactant contaminated ore were carried out using conditions very similar to those employed in the ore processing plants. The results of these experiments showed that all tested surfactants adversely affected the flotation results.

Following that finding, an investigation began to study possible means to eliminate the detrimental effect of the surfactants on flotation.

Several tests carried out to adjust the amount of flotation reagents to reduce the excess froth and lack of selectivity created by the presence of surfactants did not bring any significant improvement in the flotation results.

Contacts were also made with the manufacturers of the wetting agents to study possible development of anti-surfactants or to find conditions under which the wetting agents would be destroyed or annihilated prior to flotation. None have assumed a commitment to pursue this route of investigation yet.

Research work initiated in our laboratory succeeded however in developing a technique by which the surfactants can be adsorbed on activated carbon and eliminated from the process before flotation, with no adverse effect on metallurgical results.

The technique is very simple and requires only a small capital investment with minimal change in the plant process.

Finding a method to eliminate the adverse effect of the surfactants on the mineral beneficiation process has opened wide the field of investigation for use of wetting agents for better dust control in underground sulphide ore mines.

This report covers the results of the study to eliminate the detrimental effect of the wetting agents in the flotation of Opemiska copper ore.

OUTLINE OF INVESTIGATION

Among the wetting agents investigated in this study for dust suppression, the following surfactants were selected:

Reagent 8A04 supplied by Alchem Inc.
Reagent BL214 supplied by G.A.F.
Reagent 5753-11-1 supplied by Dow Corning

Flotation tests carried out with Opemiska copper ore showed that all three surfactants adversely affected the metallurgical results.

Investigations were then initiated to eliminate the surfactants detrimental effect.

Alchem 8A04 wetting agent was chosen to perform the detailed investigation since its presence in the ore proved to be somewhat less detrimental to flotation than that of the other tested surfactants. However, once the technique to annihilate the adverse effect of the surfactants was established, the response of the other two surfactants to this method was verified.

OBJECTIVES OF THE INVESTIGATION

The objectives of this investigation were:

1. To determine the effect of surfactants used as dust suppressors on flotation results of Opemiska copper ore; and
2. To develop a method to eliminate the detrimental effect of the dust-suppressing surfactants on flotation results.

SUMMARY OF RESULTS

The Opemiska copper ore, contaminated with wetting agents in the amount assumed to be used for dust suppression, was subjected to flotation under conditions similar to those applied in the industrial plant. The results of the tests indicated that the wetting agents adversely affected the flotation results, particularly the grade of the copper concentrate which dropped drastically.

A technique was then developed to annihilate the detrimental effect of the wetting agents on flotation metallurgy. This technique consisted in contacting the slurry after grinding with a special brand of activated carbon for a certain period of time. During this conditioning stage, performed at relatively low rpm, the surfactants were adsorbed on the activated carbon. The carbon loaded with surfactant was removed from the slurry by screening.

The flotation reagents were then added and copper flotation took place without difficulty. The grade and recovery of copper in the concentrate were similar to those obtained when no wetting agents were sprayed on the ore. The technological scheme of surfactants removal by carbon adsorption technique is given in Fig. 1.

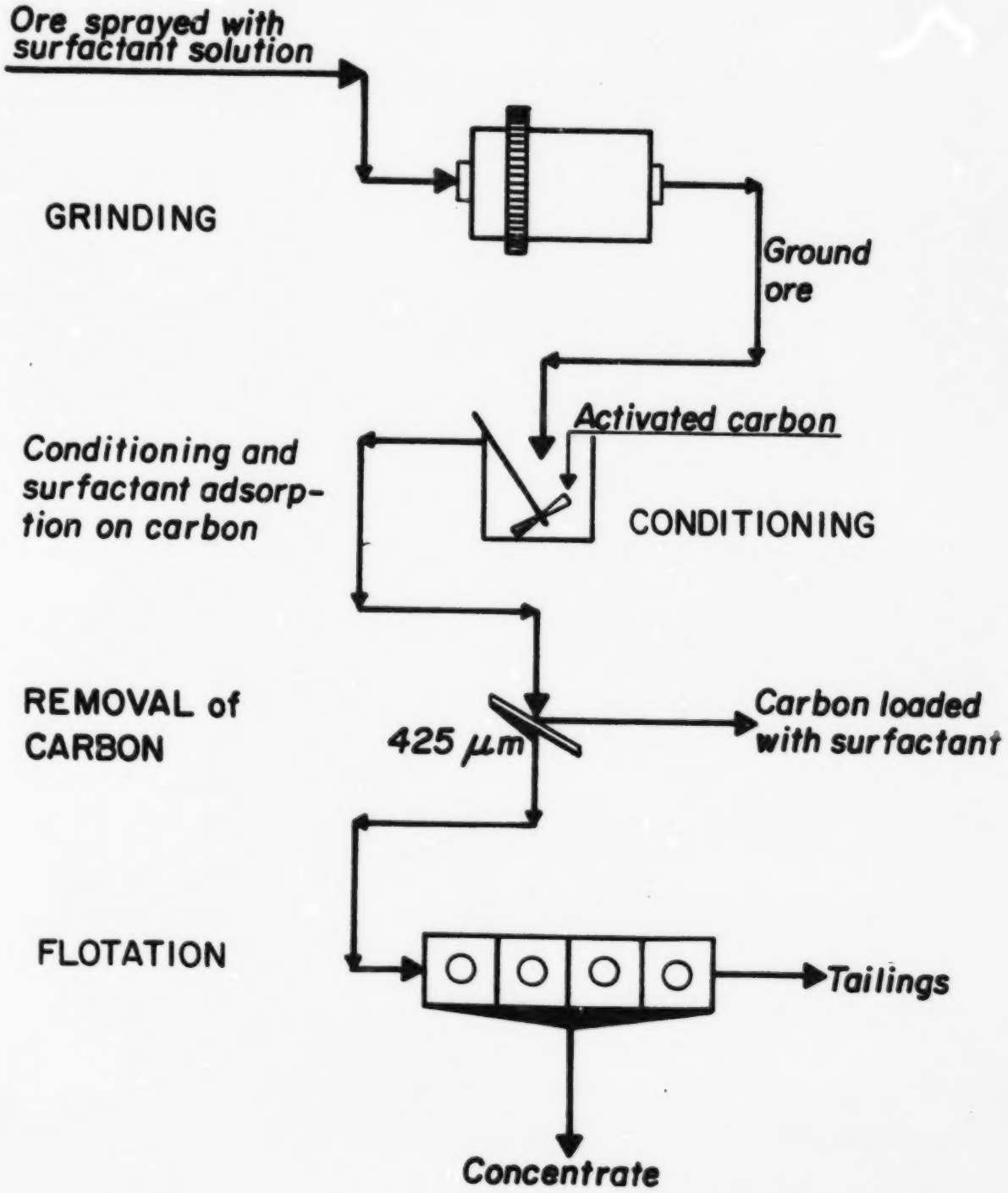
The flotation results of surfactants-contaminated-ore with and without wetting agents removal as compared with flotation of non-contaminated ore are presented in Table 1.

The results of these tests clearly indicated that in the presence of surfactants the grade of the concentrate dropped below 20% Cu. However, by applying the carbon adsorption technique the copper assay and recovery in the concentrate were similar (at least for Alchem and Dow reagents) to those obtained with non-contaminated ore.

Table 1 - Summary of results

Surfactant		Treatment			Metallurgical results		
Type	L/t	Technique	Carbon added kg/t, ore	Carbon lost kg/t, ore	% wt	% Cu	% Rec. Cu
None	-	None	-	-	18.2	24.73	95.3
	50	None	-	-	24.0	18.20	97.3
Alchem	50	Carbon adsorption	20.0	1.0	20.1	24.91	96.6
8A04	10	Carbon adsorption	1.0	0.05	21.8	23.61	96.9

Figure l. SURFACTANT ADSORPTION AND REMOVAL



To prove the efficiency of the method to eliminate the wetting agents detrimental effect, the ore was sprayed, for most of the tests, with an excessive amount of surfactants solution (2% concentration), i.e., 50 L/t ore, although standard operating conditions to suppress the dust requires a spray of only 10 L solution per tonne of ore.

The efficiency of surfactants adsorption was in direct rapport with carbon addition and contact time. However, carbon losses due to attrition and abrasion were directly related to the length of the conditioning time.

Since carbon can be regenerated and reused it was important to try to minimize carbon losses rather than carbon addition. That was accomplished by using large additions of carbon for a very short conditioning time rather than small carbon addition for long contact time. In this way, under the most severe conditions (50 L/t spray) the carbon consumption (lost carbon) was 1 kg/t of ore, and under normal conditions (10 L/t spray) the carbon losses dropped below 50 g/t of ore.

It is interesting to note that a water spray addition of 10 L/t with a low surfactant concentration (0.1%), proved to be adequate for suppressing dust conditions at laboratory scale and required no special treatment for surfactants removal. The flotation results were not affected by the presence of the surfactants in the ore. It is obvious that under these conditions the cost of dust suppression using surfactants will be extremely low (estimate: less than 3¢/t).

However, the required amount and surfactant concentration of the water spray to combat dust will be determined by systematic experiments in underground operations.

CONCLUSIONS AND RECOMMENDATIONS

The research work dealing with the influence of dust-suppressing surfactants on flotation results of Opemiska copper ore led to the following conclusions:

1. Surfactants used as wetting agents adversely affected the flotation results, particularly the concentrate grade.
2. A carbon adsorption technique could eliminate the detrimental effect of the surfactants and restore the concentrate grade, even when excessive amounts of wetting agents were used.

3. Under standard spraying conditions to suppress the dust (10 L solution/t of ore and 2% solution concentration) an addition of 1 kg activated carbon/tonne of ore for 15 min contact time was required to adsorb the surfactants and eliminate their detrimental effect on flotation results. The carbon loss was less than 50 g/t of ore.
4. A standard 10 L/t spray of low surfactant concentration (0.1%), sufficient to suppress the dust according to the laboratory results, will not be detrimental to flotation and therefore will require no treatment to annihilate the surfactants.
5. The activated carbon used to adsorb the surfactants was supplied by Calgon Canada under the brand name of SGL 8 x 30, obtained from bituminous coal at a cost of approximately $1.40/kg.
6. The process to eliminate the surfactants by adsorption on activated carbon is very simple and requires minimal changes in the plant flowsheet. A carbon adsorption unit has to be inserted between grinding and flotation. Also, to regenerate the carbon a kiln must be installed in the plant.
7. The wetting agent selected for further tests was surfactant 8A04 manufactured by Alchem Inc. It proved to be one of the most effective dust suppressors; it was well adsorbed on activated carbon and it is presently available on the market.

The selection of several surfactants that can be used as efficient dust suppressors in sulphide ore mines and the success of the carbon adsorption technique to eliminate the detrimental effect of the wetting agents on flotation, warrant the continuation of the research effort to utilize wetting agents to control sulphide ore dust with no adverse effects in subsequent ore treatment.

The following recommendations are made for the next stage of the research program in this field:

1. Finalize the carbon adsorption technique applied to Opemiska ore by determining the maximum loading capacity of the carbon and the conditions for carbon re-activation.
2. Study the conditions to apply the carbon adsorption technique for wetting agent removal to a polyminerals, medium-high sulphide content ore.

3. Study the possibility of eliminating the detrimental effects of the surfactants by other methods.
4. Start experiments in underground mines to evaluate the possibility of improving dust control by using the selected surfactant Alchem 8A04 in the spray water. Priority should be given to the experiments using low surfactant concentration at minimum water spray, conditions under which removal of the surfactants before subsequent flotation might not be required. Experiments should begin in the Opemiska copper mine and continue in poly-sulphide mines when the technique to eliminate surfactants from this type of ore will be finalized.

   Other surfactants, supplied by DOW and G.A.F. should also be investigated as potential dust suppressors.
5. Verify the technique to eliminate the wetting agents on a larger scale and in continuous operation.

DETAILED DESCRIPTION OF THE TESTWORK

Testwork was carried out on a second lot of surfactants (first lot results published in 1983) to investigate and select more and possibly better dust suppressors and to determine the influence of these wetting agents on flotation results of Opemiska copper ore.

Since all the selected surfactants used as dust suppressors adversely affected the flotation results, testwork was further performed to eliminate their detrimental effect. Again this work was carried out on Opemiska copper ore.

The conditions and results of this investigation are further described in detail.

ORE SAMPLE

The Opemiska copper ore sample was supplied by Falconbridge Corporation, Division Opemiska of Chapais, Québec. The ore has a low sulphides content and copper is the only metal recovered in the flotation plant.

The ore sample preparation for chemical assay and testwork was described in the 1983 Report (1). The chemical assay of the head sample is given in Table 2.

Table 2 - Sample head assay

Constituent	Pb	Cu	Zn	S	Fe	SiO_2
%	0.02	4.39	0.08	5.27	15.98	41.83

WETTING AGENTS USED IN THE TESTWORK

The wetting agents received in the second lot, their suppliers and some chemical characteristics are indicated in Table 3.

Table 3 - Wetting agents

Reagent	Manufacturer	Chemical nomenclature	Surfactant type
X2-8063	Dow Corning	Aminofunctional silicon emulsion	Cationic
193		Silicone glycol copolymers	Non-ionic
E-5753-11-1		Silicone glycol copolymers	Non-ionic
E-5753-11-2		Silicone glycol copolymers	Non-ionic
E-5753-11-3		Silicone glycol copolymers	Non-ionic
E-5753-11-5		Silicone glycol copolymers	Non-ionic
Antarox BL-214	G.A.F.	Modified linear aliphatic polyethers	Non-ionic
Antarox BL-225		Modified linear aliphatic polyethers	Non-ionic
Antarox BL-330		Modified linear aliphatic polyethers	Non-ionic
8A07	Alchem Inc.	Polyelectrolite-chloride	Anionic
8A04		Surfactant	Non-ionic
8A08		Latex polyelectrolite	Non-ionic
8820		Acrylic, ethylene glycol, dioctyl sulfosuccinate mixture	Non-ionic

More detailed information about the physico-chemical characteristics of these surfactants, their present application and material safety data are kept available for examination on section files.

This wetting agents were subjected to a number of tests to determine their ability to perform as sulphide ore dust suppressors.

Selection of the most suitable wetting agents for this application was based on the following laboratory determinations:

1. Wetting ability, evaluated on the basis of the ore dust sinkage rate, expressed in mg/s and determined as the required time in seconds, for wetting and sinking a quantity of 1000 mg sulphide ore dust, spread on the surface of the reagent solution.
2. Foam volume and persistency evaluated by measuring the maximum volume of foam produced by the surfactants under certain conditions and the foam volume variation at successive time intervals.
3. Solubility of the surfactants determined at ambient temperature under various concentration.

Also, in selecting the optimum wetting agents, consideration was given to safety data information supplied by the manufacturers in terms of health hazard and fire or explosion risk that could result by handling and operating the surfactants.

The procedures used to evaluate the surfactants properties were described in the 1983 study (1).

Detailed information on all the experiments conditions and results carried out to evaluate and select the surfactants are kept available for examination on section files.

The results of the testwork carried out to evaluate the wetting agents as potential sulphide ore dust suppressors are summarized in Table 4.

An overall selection was made on the basis of surfactants response to various testing conditions. The required mark to pass a test was in most of the cases arbitrarily chosen, dictated by the performances of the majority of the reagents with the intention to eliminate those that gave the most inferior results.

The most decisive criterion in selecting the surfactants was their ability to perform as wetting agents for sulphide ore dust, a property that was put in evidence by their sinkage rate. However, those reagents which exhibited excessive foaming properties, showed very low solubility in water or required special precautions in handling and operation were eliminated in the final selection regardless of their wetting ability.

One wetting agent was chosen from each group of surfactants supplied by Dow Corning, G.A.F. and Alchem.

Table 4 - Summary of results to evaluate the surfactants as dust suppressors

Surfactant	Sinkage			Foaming				Solubility			Safety		Overall selection
	Surf. conc. %	Rate mg/s	Select.	Surf. conc. %	Max. foam Sol'n vol.	Foam 30' Foam 1'	Select.	Surf. conc. %	Sol'n clarity	Select.	Special precaution	Select.	
X2-8063	0.1	11	No	2.0	2.75	0.24	Yes	2.0	cloudy	Yes	Unknown	-	Rejected
193	0.1	333	No	2.0	3.75	0.49	No	2.0	clear	Yes	Unknown	-	Rejected
E-5753-11-1	0.1	500	Yes	2.0	1.10	0.86	Yes	2.0	cloudy	Yes	Unknown	-	Accepted
E-5753-11-2	0.1	1000	Yes	2.0	2.50	0.52	Yes	2.0	cloudy	Yes	Unknown	-	Rejected
E-5753-11-3	0.1	1000	Yes	2.0	>5.00	0.30	No	2.0	cloudy	Yes	Unknown	-	Rejected
E-5753-11-5	0.1	1000	Yes	2.0	0.75	0.92	No	2.0	cloudy	Yes	Unknown	-	Rejected
BL-214	0.1	1000	Yes	2.0	0.15	0.50	Yes	2.0	clear	Yes	None	Yes	Accepted
BL-225	0.1	1000	Yes	2.0	2.00	0.08	Yes	2.0	cloudy	Yes	None	Yes	Rejected
BL-330	0.1	1000	Yes	2.0	1.50	0.30	Yes	2.0	clear	Yes	Avoid vapours	No	Rejected
8A04	0.1	500	Yes	2.0	3.00	0.69	Yes	2.0	clear	Yes	None	Yes	Accepted
8A07	0.1	500	Yes	2.0	>5.00	1.00	No	2.0	clear	Yes	Avoid vapours	No	Rejected
8A08	0.1	<1	No	2.0				2.0	cloudy	Yes	None	Yes	Rejected
8820	0.1	33	No	2.0	1.75	0.29	Yes	2.0	cloudy	Yes	Avoid vapours	No	Rejected

The following surfactants were selected to be examined in the next stage of investigation:

E-5753-11-1 supplied by Dow Corning

BL-214 supplied by G.A.F.

8A04 supplied by Alchem Inc.

EFFECT OF WETTING AGENTS ON FLOTATION RESULTS

A sample of Opemiska copper ore was used to examine, in laboratory scale, the influence of the dust-suppressing surfactants on the flotation results.

To simulate the exposure of the ore to the wetting agents used as dust suppressors, the surfactants were added to the dry sample prior to the grinding stage. Solution of 2% wetting agents was used in the amount varying from 2.5 to 50 L solution per tonne of ore. About 10 L/t is considered an adequate spray to suppress the dust in an underground mine.

After grinding, the slurry containing the surfactants was transferred to a flotation cell and the copper flotation was performed under the conditions similar to those employed in the industrial plant. The flotation results with and without surfactants addition were then compared.

To simplify the testwork the copper flotation was limited to an open rougher-scavenger circuit, the rougher concentrate representing the final copper product.

The grinding and the type of flotation reagents used in this testwork were similar to those employed in Opemiska concentrator.

The following conditions were used for the laboratory testwork:

Grinding:	65%-74 µm	
Flotation:	Rougher	Scavenger
pH	9.5	9.3
Reagents (g/t)		
lime	300	-
xanthate, Kamyl	25	20
TEB (triethoxybutane)	80	80
Time, minutes	6.5	6

The detailed conditions and results of copper flotation tests, with and without surfactants are kept available for examination on section files.

A summary of the most significative flotation results (Cu grade and recovery in the rougher concentrate) obtained in the presence of surfactants are presented in Table 5.

When no surfactants were used the results of the flotation for the rougher concentrate were:

Assay: 24.73% Cu

Recovery of copper: 95.3%

All the surfactants tested on Opemiska ore had a detrimental effect on copper flotation, by drastically reducing the grade of the concentrate. The negative effect on flotation results was in direct rapport with the amount of surfactant solution sprayed on the ore sample.

The deterioration of the concentrate grade was attributed to the excessive amount of froth produced by the surfactants. This has made the slimes and some gangue minerals to become entrained in the froth and float along with the copper minerals, reducing the Cu content of the concentrate. It may also be possible that during the grinding and conditioning the surfactants have been indiscriminately adsorbed at the surface of the minerals (copper carriers and gangue) interfering with the selective adsorption of the collectors.

Since the surfactant 8A04 manufactured by Alchem Inc. affected the flotation results to a lesser extent than the other two, it was decided to use this reagent for the research work aimed to eliminate the detrimental influence of the surfactants-dust-suppressors on flotation.

However, in the final stage of the research work the results obtained with Alchem reagent were compared with those given by using Dow's and G.A.F.'s reagents.

INVESTIGATION TO ANNIHILATE THE WETTING AGENTS EFFECT

Research work to eliminate the adverse effect of the surfactants on Opemiska ore flotation was initiated pursuing three lines of investigation:

1. Adjustment of flotation reagents regime to accommodate the presence of surfactants.
2. Development of anti-surfactants reagents or conditions to destroy the wetting agents.
3. Removal of the surfactants from the slurry prior to flotation.

Table 5 - Summary of flotation results in the presence of surfactants

	2.5 L/t		5.0 L/t		10 L/t		50 L/t	
Surfactant	Assay % Cu	% Recov. Cu	Assay % Cu	% Recov. Cu	Assay % Cu	% Recov. Cu	Assay % Cu	% Recov. Cu
E-5753-11-1 Dow	19.93	96.3	20.43	97.0	18.40	97.4	16.09	95.8
BL-214 G.A.F.	21.42	94.9	20.07	97.2	19.14	96.6	17.09	97.6
8A04 Alchem	24.75	94.6	23.33	95.6	21.06	95.2	18.20	97.3

The adjustment of the flotation reagents, particularly the frother, was tried to compensate for the foaming effect of the surfactants. Although the amount of froth was reduced to certain extent, no improvement of the copper concentrate was obtained. Therefore, this line of investigation was abandoned. The conditions and results of this limited volume of testwork was not reported.

The manufacturers of the selected surfactants were contacted to investigate possible conditions for surfactants destruction after their use as dust suppressors. No positive response has been received yet on this route of investigation.

Since these two routes of investigation could not provide a method to restore the grade of the flotation concentrate in the presence of the surfactants, the research work was directed toward finding means to remove the wetting agents from the slurry, before the addition of the flotation reagents.

The investigation conducted in this direction succeeded in developing a technique by which the wetting agents could be removed from the slurry by adsorption on activated carbon. By applying this procedure the detrimental effect of the wetting agents was annihilated.

The conditions and results of this testwork are further described.

1. Carbon adsorption procedure

The concept of removing the surfactants sprayed on the ore by using the carbon adsorption technique was based on the idea that organic matters can be adsorbed on certain types of activated carbon. If the surfactants-contaminated ore is put in contact with activated carbon, the wetting agents which are organic chemicals can be adsorbed on carbon. Then, the carbon loaded with surfactants can be removed and the decontaminated ore will be further processed without difficulty.

The developing of carbon adsorption technique for surfactants removal required detailed study of several conditions; e.g. type of activated carbon, addition point, amount of carbon and contact time, method of carbon removal, etc.

To find a proper brand of carbon for this application a search of the various types of activated carbon available on the market was conducted. Several carbon manufacturers were contacted and the final choice was based on products specifications and recommended usages.

The place of carbon addition and removal was carefully examined to avoid possible adsorption of the flotation reagents of organic composition. For this reason, in most of the tests the carbon was kept in contact with the ore and removed from the slurry prior to the addition of flotation organic reagents (collector and frother).

The surfactants adsorption was examined under carbon addition in the grinding stage and after grinding.

When carbon was added in the grinding mill it was ground with the ore, the surfactants adsorption took place during grinding and the carbon was recovered by flotation in the copper concentrate. It was not possible to selectively float the carbon from the copper.

In another series of tests the carbon was added after grinding and was kept in contact with the ore in a conditioning stage for certain amounts of time. The surfactants adsorption took place in the conditioning stage. After that the carbon which was much coarser than the ground ore was separated from the slurry by screening. The surfactants-decontaminated slurry was then conditioned with flotation reagents and the copper concentrate was collected.

The addition of carbon after grinding was the preferred route to obtain the adsorption of surfactants since in this way the carbon can be recuperated and reused.

Therefore, more detailed investigation to determine the optimum carbon addition and contact time was carried out with carbon added after the grinding stage. Various additions of carbon from 1 to 20 kg carbon/tonne of ore was tried, under conditioning time of 15 min to 2 h. Although the conditioning stage was performed at low rpm to avoid carbon destruction by attrition the amount of abraded carbon increased significantly with the length of contact time.

All the testwork to determine optimum conditions for surfactants removal by adsorption on activated carbon was carried out using Alchem reagent 8A04. In the final stage, the response of the other two selected surfactants to carbon adsorption technique was verified.

The technique of surfactants adsorption using two variants of carbon addition is briefly described below.

A. Carbon addition in the grinding stage

The following steps were used:

1. The ore was sprayed with 2% solution of surfactant, in the amount of 10-50 L/t, to simulate the exposure of the mined ore to dust suppressors.
2. The contaminated ore was placed in the grinding mill and activated carbon in the amount of 10 kg/t was added to adsorb the surfactant. The grinding was performed under usual conditions.
3. The ground ore was transferred to the flotation cell, the flotation reagents were added and the copper concentrate was collected under usual conditions. The ground carbon loaded with surfactant reported in the copper concentrate. No additional reagents for carbon flotation were required.

Since the frother TEB (triethoxybutane) was to some extent adsorbed on carbon during conditioning it was replaced by MIBC (metylisobutycarbinol) which did not present this problem.

The xanthate did not exhibit any adsorption effect.

B. Carbon addition after the grinding stage

The following steps were used:

1. The ore was sprayed with 2% solution of surfactant, in the amount of 10-50 L/t, to simulate the exposure of the mined ore to dust suppressors.
2. The contaminated ore was placed in the grinding mill and the grinding was performed under usual conditions.
3. The ground ore was transferred to a conditioner and the carbon was added in the amount of 1 to 20 kg/t. The contact time between carbon and slurry was maintained for 15 min to 2 h under low rpm to reduce carbon degradation.
4. After conditioning, the carbon loaded with surfactant was removed by screening on a 425 µm screen. The ground ore was much finer than the carbon and it passed through the 425 µm screen. As a precaution, to avoid the possible presence of few coarse ore particles in the carbon, the ground ore was screened on 425 µm before conditioning with activated carbon.
5. The surfactant-decontaminated slurry was transferred to a flotation cell, the flotation reagents were added and copper flotation

was performed as usual. Again, to avoid any possible adsorption of the frother by the degraded carbon left in the slurry after screening, the TEB was replaced by MIBC.

2. Results

The results of Opemiska copper flotation, obtained after using the carbon adsorption technique to decontaminate the surfactant sprayed ore are presented below for each variant.

A. Carbon addition in the grinding stage

Two tests were carried out with carbon added in the grinding mill. Detailed conditions and results of these tests are given in Appendix A.

In one of the tests it was tried to float the carbon with kerosene prior to copper flotation. It was not possible to obtain two distinctive concentrates since some of the copper floated with the carbon. Therefore, carbon and copper were combined in one product.

In the other test, kerosene was omitted and only the reagents required for copper flotation were added. Carbon and copper were collected in the same product.

The results of these tests are summarized in Table 6 and compared with those obtained when no wetting agents were used and with the test for which the surfactants adsorption was not performed.

The results of these tests indicated that the variant of surfactant adsorption technique with carbon added in the grinding succeeded to annihilate the negative effect of the wetting agents on copper concentrate grade.

The disadvantage of this variant is that the carbon is ground with the ore and cannot be recuperated and reused.

Table 6 - Summary of conditions and results, carbon added in the grinding

Surfactant L/t	Flotation	Carbon g/t	Rougher concentrate		
			Weight %	Assay % Cu	% Dist. Cu
None	Copper	None	18.2	24.73	95.3
50	Copper	None	24.0	18.20	97.3
50	Carbon + Cu	10	15.6	25.54	95.0
50	Collective (C, Cu)	10	16.8	25.35	96.2

B. Carbon addition after the grinding stage

The alternative of surfactant adsorption with carbon added after the grinding and therefore reusable was considered economically more attractive than the variant with non-recoverable carbon.

Detailed testwork carried out in the recoverable carbon variant focussed on investigating the influence of two parameters: amount of carbon addition and contact time.

Complete results of this testwork are presented in Appendix B. A summary of the work conditions and results are given in Table 7.

The results of these tests indicated that a certain relationship between carbon addition and contact time must exist in order to annihilate the surfactants negative effect and to restore the copper grade and recovery in the flotation concentrate.

For each carbon addition an optimum conditioning time was determined, conditions under which the copper grade and recovery in the flotation concentrate were similar to those obtained when no surfactant was sprayed on the ore. To annihilate the negative effect of surfactants the following relationship between carbon addition and contact time was established:

Carbon addition of 5 g requires 90 min contact time
Carbon addition of 7 g requires 60 min contact time
Carbon addition of 10 g requires 45 min contact time
Carbon addition of 20 g requires 15 min contact time

The relationship between carbon addition and contact time was plotted in Fig. 2. The carbon losses by abrasion, during various conditioning times, regardless of flotation results, were reported in Table 8. The carbon loss and contact time relationship was plotted in Fig. 2.

The carbon addition and contact time were inversely related. The same efficiency in surfactant adsorption could be obtained by using a small amount of carbon for a long conditioning time or a large carbon addition for a short contact time.

However, the carbon loss was in direct relation with the duration of contact time. Therefore, since carbon can be recovered and reused it was considered more important to minimize the carbon loss rather than the carbon addition.

Table 7 - Summary of conditions and results, carbon addition after grinding

Carbon		Cu rougher concentrate		
Amount kg/t	Contact min.	Weight %	Assay % Cu	% Dist. Cu
1	60	23.4	20.10	96.9
5	60	19.9	22.96	96.8
	90	19.4	25.26	96.2
	105	18.8	26.50	95.6
	120	18.8	25.87	95.9
7	45	20.3	24.66	96.5
	60	17.0	26.24	94.8
	90	19.2	24.90	95.7
	120	16.5	28.17	91.7
10	10	20.4	22.19	96.2
	20	19.1	22.04	96.2
	30	18.5	23.48	95.5
	45	18.1	24.37	95.2
	60	15.4	27.00	91.9
	120	12.3	29.49	83.1
20	15	20.1	24.91	96.6
	30	15.8	28.58	91.0
	45	17.6	26.72	95.0
	60	16.7	27.93	94.1
No surfactant spray		18.2	24.73	95.3

Table 8 - Carbon addition and loss versus contact time

Carbon-slurry contact time min.	Carbon Addition kg/t	Carbon Loss kg/t	Carbon Loss %	Carbon-slurry contact time min.	Carbon Addition kg/t	Carbon Loss kg/t	Carbon Loss %
10	10	0.4	4		7	0.5	7
	10	0.7	7	45	10	0.6	6
15	20	1.1	6		20	1.5	8
	20	1.0	5		10	1.3	13
	20	1.3	7	60	10	1.2	12
	10	1.0	10		20	2.5	13
30	10	0.6	6	90	7	0.8	11
	20	2.0	10	120	10	1.7	17

Consequently, a carbon addition of 20 kg/t will result in a carbon loss of approximately 5% or 1 kg/t. This loss could be further reduced by choosing a proper conditioning system and by trying to find other sorts of carbon more resistant to attrition and abrasion.

Also, it should be noted that the required amount of carbon and contact time to annihilate the negative effect of surfactants was determined under excessive addition of wetting agents, i.e., 50 L, solution 2%, per tonne of ore. However, a more realistic spray of wetting agents to suppress dust would be only 10 L/t.

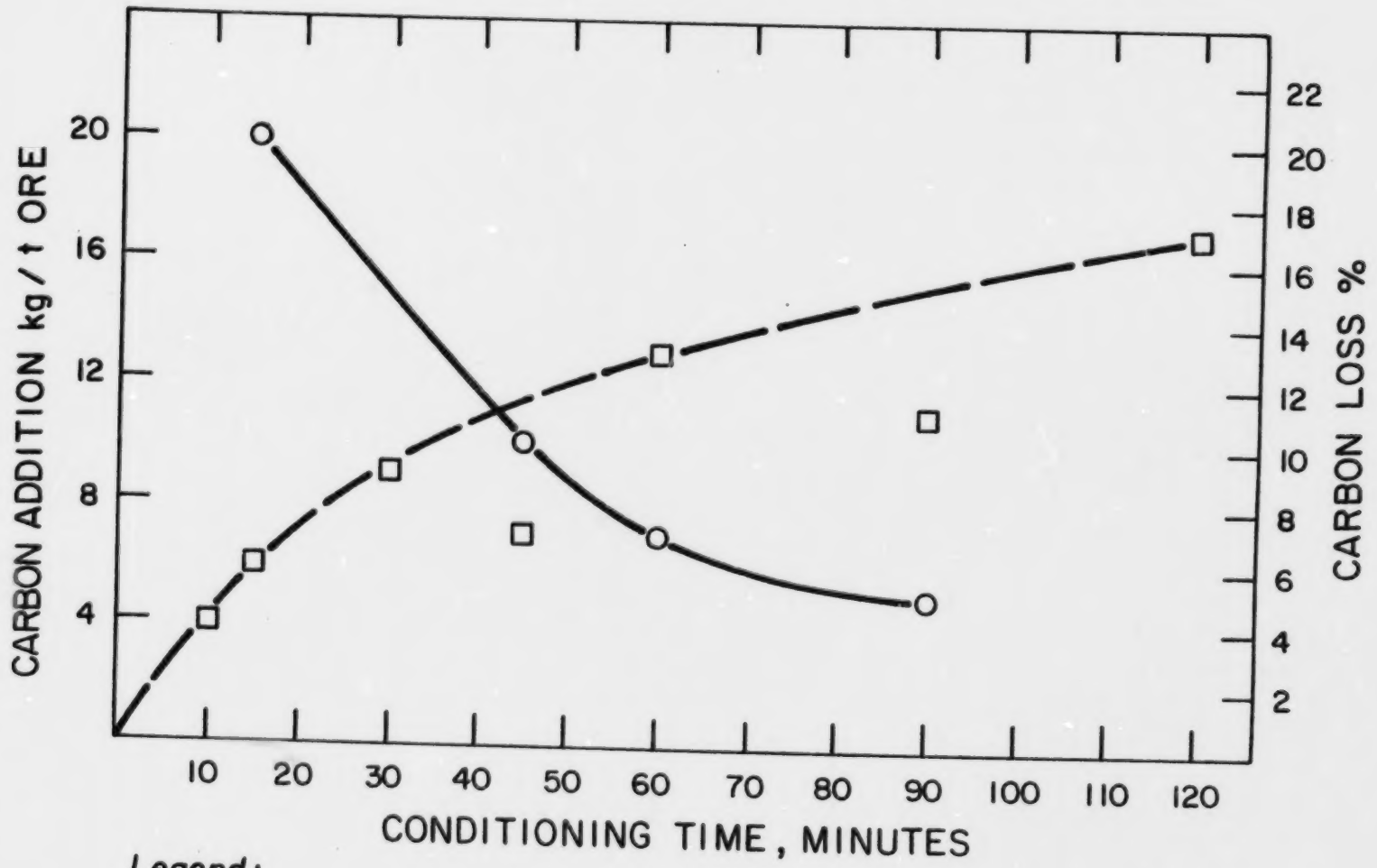
Several tests were carried out to determine the required carbon addition to annihilate a surfactant spray of 10 L/t. The contact time for all these tests were kept to a minimum.

Detailed conditions and results of these tests are given in Appendix C. A summary of the results is presented in Table 9.

Table 9 - Results under 10 L/t surfactant spray

Surfactant adsorption		Flot. rougher conc.		
Contact time minutes	Carbon Added, kg/t	Weight %	Assay % Cu	% Dist. Cu
15	20	17.4	27.28	93.1
15	10	19.9	24.00	95.3
15	5	20.7	23.85	96.6
15	1	21.8	23.61	96.9

Figure 2 CARBON ADDITION AND LOSS vs CONTACT TIME



Legend:

Carbon addition vs contact time : ——————

Carbon loss vs contact time : —— ——

The data of this series of tests showed that under 10 L/t surfactant spray even 1 kg/t carbon addition was enough to decontaminate the ore and to restore the copper grade in the flotation concentrate. The carbon loss for 1 kg/t addition was less than 50 g/t.

Another important element to be considered, in minimizing the cost of surfactant use for dust control and surfactant decontamination before flotation is the possibility of reducing the wetting agent concentration in the spray solution below 2%. For practical purpose the surfactant removal testwork was carried out using 2% solution of wetting agent. However, the tests performed to determine the ability of the surfactants to suppress dust indicated that for selected agents, the dust suppressing efficiency remained unchanged under various solution concentration down to 0.1%.

The optimum concentration of surfactants in the water spray for dust suppression will actually be determined during the experiments that will be carried out in underground mines. It is obvious that a decrease in surfactant concentration or in the amount of solution spray will result in a corresponding reduction of the cost to annihilate the negative effect of the wetting agents.

An experiment carried out with ore sprayed with solution of low surfactant concentration (0.1%) in the amount of 10 L/t, conditions which could be quite adequate to suppress the underground dust, indicated that the flotation took place without any difficulty, the copper grade and recovery in the rougher concentrate remaining unaffected by the presence of the wetting agents. In this case there was no need to use the carbon adsorption technique for surfactant removal.

The results of this test are given in Table 10 as compared with those obtained with uncontaminated ore.

Table 10 - Flotation results under low surfactant concentration

Surfactant 8A04		Copper rougher conc.		
Conc.	Amount	Weight	Assay %	% Dist.
%	L/t	%	Cu	Cu
-	Nil	18.2	24.73	95.3
0.1	10	19.5	23.68	96.2

It is estimated that the use of surfactant to suppress dust under these conditions will cost below 3¢/t of ore. Also, the decontamination of the ore prior to flotation will not be required.

The response to carbon adsorption technique of the other two selected wetting agents supplied by Dow Corning and G.A.F., was verified.

Solutions of 2% concentration in wetting agents was sprayed on the ore in the amount of 10 L/t and 50 L/t.

The carbon adsorption technique was then used to annihilate the surfactants. The addition of activated carbon was 10 kg/t for the 10 L/t solution spray and 20 kg/t carbon for 50 L/t solution. In both cases the contact time between carbon and slurry was kept to 15 min.

After surfactants adsorption the carbon was removed by screening and the copper flotation was performed under standard conditions.

Detailed conditions and results of the flotation tests carried out after decontamination from Dow's and G.A.F.'s surfactants are presented in Appendix D.

A summary of these results compared with those obtained when no surfactants were added or when carbon adsorption was not applied is given in Table 11.

Table 11 - Results with Dow and G.A.F. surfactants

Surfactant		Carbon addition		Copper rougher conc.		
	Sol'n 2%	Carbon	Condition	Weight	Assay %	% Dist.
Type	L/t	kg/t	min.	%	Cu	Cu
None	-	-	-	18.2	24.73	95.3
Dow Corning	50	Nil	Nil	25.1	16.09	95.8
E-5753-11-1	10	10	15	20.8	24.04	97.1
	50	20	15	18.9	24.66	95.1
G.A.F.	50	Nil	Nil	28.5	17.09	97.6
BL-214	10	10	15	21.8	23.43	97.0
	50	20	15	19.6	22.59	96.5

The data of these tests showed that the copper grade in the flotation concentrate was corrected after surfactants adsorption on activated carbon.

Consequently, the carbon adsorption technique developed for the Alchem surfactant removal could be used to decontaminate the ore sprayed with Dow's and G.A.F.'s wetting agents tried in these experiments.

There is a good possibility that the carbon adsorption-decontamination technique can be used to annihilate some other surfactants used as dust suppressors. However, to remain on the safe side, before assessing a wetting agent as potential dust suppressor its response to the carbon adsorption technique should be evaluated.

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REFERENCE

1. Cristovici, M.A. and Lachapelle, P. "Investigation to select suitable wetting agents as sulphide ore dust suppressants and to study their influence on the flotation process"; Division Report MRP/MSL 83-66 (IR); CANMET, Energy Mines and Resources; 1983.

APPENDIX A

CARBON ADDITION IN THE GRINDING STAGE

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Copper and carbon collective flotation

TEST NO: 87

					Reagents - g/t								
	Time	%			Carbon		Xanthate				Wt	Assay %	% Dist.
Operation	min.	Solids	pH	Rpm	kg/t	Lime	350	MIBC	Remarks	Product	%	Cu	Cu
Grinding	18	65		75	10				50 L/t, 2% sol'n of	Rougher + scavg. conc.	16.8	25.35	96.2
Conditioning	1		9.1	1500					surfactant 8A04	Tails	83.2	0.20	3.8
Conditioning	3		10.4			300			sprayed on the ore	Head (calc.)	100.0	4.42	100.0
Conditioning	3						25		prior to grinding				
Conditioning	1							50					
Rougher flot.	3								Carbon added in the				
Conditioning	3						20		grinding				
Conditioning	1							10					
Scavg. flot.	3								Carbon and copper were				
									floated together				

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Carbon-copper selective flotation

TEST NO: 88

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Kero-sene	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75	10					50 L/t, 2% sol'n of
Conditioning	1		9.1	1500						surfactant 8A04
Conditioning	3					50				sprayed on the ore
Conditioning	1								100	prior to grinding
Carbon flot.	3									
Conditioning	3		10.4				300			
Conditioning	3							25		Carbon added in
Conditioning	1								50	the grinding
Copper flot.	3									
Conditioning	3							20		Carbon was floated
Conditioning	1								50	first then the
Scavg. flot.	4									copper

Product	Wt %	Assay % Cu	% Dist. Cu
Carbon + Cu + Scavg. conc.	15.6	25.54	95.0
Tails	84.4	0.25	5.0
Head (calc.)	100.0	4.20	100.0

APPENDIX B

CARBON ADDITION AFTER GRINDING

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 92

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65							50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	10				10				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3								
Conditioning	1						25		Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents
Rougher flot.	5							50	
Conditioning	3								
Conditioning	1						20		
Scavg. flot.	4							50	

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	20.4	22.19	96.2
Scavg. conc.	2.8	2.87	1.7
Tails	76.8	0.13	2.1
Head (calc.)	100.0	4.71	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 93

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	20				10				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							50	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	19.1	22.04	96.2
Scavg. conc.	2.4	2.96	1.6
Tails	78.5	0.12	2.2
Head (calc.)	100.0	4.37	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 94

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	30				10				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	18.5	23.48	95.5
Scavg. conc.	2.6	3.59	2.1
Tails	78.9	0.14	2.4
Head (calc.)	100.0	4.54	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 95

					Reagents - g/t								
	Time	%			Carbon		Xanthate				Wt	Assay %	% Dist.
Operation	min.	Solids	pH	Rpm	kg/t	Lime	350	MIBC	Remarks	Product	%	Cu	Cu
Grinding	18	65		75					50 L/t, 2% sol'n of	Rougher conc.	18.1	24.37	95.2
Conditioning	1		9.2	1200					surfactant 8A04	Scavg. conc.	3.5	3.40	2.6
Conditioning	45				10				sprayed on the ore	Tails	78.4	0.13	2.2
Carbon removal	-								prior to grinding	Head (calc.)	100.0	4.63	100.0
Conditioning	3		10.4	1500		300							
Conditioning	3						25		Carbon added in the				
Conditioning	1							50	cell, conditioned at				
Rougher flot.	5								low rpm and then				
Conditioning	3						20		removed by screening				
Conditioning	1							50	prior to addition of				
Scavg. flot.	4								flotation reagents				

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 96

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	60				10				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							50	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	15.4	27.00	91.9
Scavg. conc.	4.6	4.83	4.9
Tails	80.0	0.18	3.2
Head (calc.)	100.0	4.52	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 97

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	120				10				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							50	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	12.3	29.49	83.1
Scavg. conc.	6.2	10.81	15.4
Tails	81.5	0.08	1.5
Head (calc.)	100.0	4.36	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 104

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC
Grinding	18	65		75				
Conditioning	1		8.9	1200				
Conditioning	60				1			
Carbon removal	-							
Conditioning	3		10.2	1500		300		
Conditioning	3						25	
Conditioning	1							80
Rougher flot.	5							
Conditioning	3						20	
Conditioning	1							50
Scavg. flot.	4							

Remarks: 50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding

Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	23.4	20.10	96.9
Scavg. conc.	1.2	3.69	0.9
Tails	75.4	0.14	2.2
Head (calc.)	100.0	4.85	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 105

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.0	1200					surfactant 8A04
Conditioning	60				5				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.2	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							80	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	19.9	22.96	96.8
Scavg. conc.	2.2	2.37	1.1
Tails	77.9	0.13	2.1
Head (calc.)	100.0	4.72	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 106

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	60				7				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	17.0	26.24	94.8
Scavg. conc.	3.6	3.48	2.7
Tails	79.4	0.15	2.5
Head (calc.)	100.0	4.70	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 107

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		8.9	1200					surfactant 8A04
Conditioning	90				5				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.2	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							80	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	19.4	25.26	96.2
Scavg. conc.	2.8	3.11	1.7
Tails	77.8	0.14	2.1
Head (calc.)	100.0	5.09	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 108

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	105				5				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							50	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	18.8	26.50	95.6
Scavg. conc.	3.5	3.49	2.3
Tails	77.7	0.14	2.1
Head (calc.)	100.0	5.21	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 109

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	120				5				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							50	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	18.8	25.87	95.9
Scavg. conc.	3.2	3.18	2.0
Tails	78.0	0.14	2.1
Head (calc.)	100.0	5.07	100.0

SAMPLE: Opemiska copper ore

TEST NO: 110

OBJECT OF TEST: Determine optimum carbon addition and contact time

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	15				20				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							50	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	20.1	24.91	96.6
Scavg. conc.	2.2	3.11	1.3
Tails	77.7	0.14	2.1
Head (calc.)	100.0	5.18	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 111

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	30				20				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the
Conditioning	1							50	cell, conditioned at
Rougher flot.	5								low rpm and then
Conditioning	3						20		removed by screening
Conditioning	1							50	prior to addition of
Scavg. flot.	4								flotation reagents

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	15.8	28.58	91.0
Scavg. conc.	5.3	5.69	6.1
Tails	78.9	0.18	2.9
Head (calc.)	100.0	4.96	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 112

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	45				20				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	12.7	30.90	79.3
Scavg. conc.	4.9	15.90	15.7
Tails	92.4	0.30	5.0
Head (calc.)	100.0	4.95	100.0
Rougher + scavg. conc.	17.6	26.72	95.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 113

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	60				20				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	11.5	31.41	72.9
Scavg. conc.	5.2	20.26	21.2
Tails	93.3	0.35	5.9
Head (calc.)	100.0	4.96	100.0
Rougher + scavg. conc.	16.7	27.93	94.1

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 114

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	45				7				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	20.3	24.66	96.5
Scavg. conc.	2.2	3.17	1.4
Tails	77.5	0.14	2.1
Head (calc.)	100.0	5.19	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 115

					Reagents - g/t								
Operation	Time min.	% Solids	pH	Rpm	Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks	Product	Wt %	Assay % Cu	% Dist. Cu
Grinding	18	65		75					50 L/t, 2% sol'n of	Rougher conc.	19.2	24.90	95.7
Conditioning	1		9.2	1200					surfactant 8A04	Scavg. conc.	3.2	3.28	2.1
Conditioning	90				7				sprayed on the ore	Tails	77.6	0.14	2.2
Carbon removal	-								prior to grinding	Head (calc.)	100.0	4.99	100.0
Conditioning	3		10.4	1500		300							
Conditioning	3						25		Carbon added in the				
Conditioning	1							50	cell, conditioned at				
Rougher flot.	5								low rpm and then				
Conditioning	3						20		removed by screening				
Conditioning	1							50	prior to addition of				
Scavg. flot.	4								flotation reagents				

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine optimum carbon addition and contact time

TEST NO: 116

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					50 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	120				7				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added in the cell, conditioned at low rpm and then removed by screening prior to addition of flotation reagents
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	16.5	28.17	91.7
Scavg. conc.	5.1	5.50	5.5
Tails	78.4	0.18	2.8
Head (calc.)	100.0	5.07	100.0

APPENDIX C

RESULTS UNDER REDUCED AMOUNT OF SURFACTANT

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Reduce carbon addition at standard surfactant spray

TEST NO: 118

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65							10 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding Carbon added, conditioned and removed as per Test 92
Conditioning	1			9.2					
Conditioning	15				20				
Carbon removal	-								
Conditioning	3			10.4		300			
Conditioning	3						25		
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	17.4	27.28	93.1
Scavg. conc.	3.7	4.81	3.5
Tails	78.9	0.22	3.4
Head (calc.)	100.0	5.10	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Reduce carbon addition at standard surfactant spray

TEST NO: 119

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					10 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	15				10				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added, condi-
Conditioning	1							50	tioned and removed
Rougher flot.	4								as per Test 92
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	19.9	24.00	95.3
Scavg. conc.	3.1	3.91	2.4
Tails	77.0	0.15	2.3
Head (calc.)	100.0	5.01	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Reduce carbon addition at standard surfactant spray

TEST NO: 120

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					10 L/t, 2% sol'n of surfactant 8A04 sprayed on the ore prior to grinding
Conditioning	1		9.2	1200					
Conditioning	15				5				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added, conditioned and removed as per Test 92
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	20.7	23.85	96.6
Scavg. conc.	3.2	2.40	1.5
Tails	76.1	0.13	1.9
Head (calc.)	100.0	5.11	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Reduce carbon addition at standard surfactant spray

TEST NO: 122

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					10 L/t, 2% sol'n of
Conditioning	1		9.2	1200					surfactant 8A04
Conditioning	15				1				sprayed on the ore
Carbon removal	-								prior to grinding
Conditioning	3		10.4	1500		300			
Conditioning	3						25		Carbon added, condi-
Conditioning	1							50	tioned and removed
Rougher flot.	5								as per Test 92
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	21.8	23.61	96.9
Scavg. conc.	2.5	2.50	1.2
Tails	75.7	0.13	1.9
Head (calc.)	100.0	5.31	100.0

APPENDIX D

RESPONSE OF DOW AND G.A.F. SURFACTANTS TO CARBON ADSORPTION TECHNIQUE

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine Dow's surfactants response to carbon adsorption technique

TEST NO: 123

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC
Grinding	18	65		75				
Conditioning	1		9.2	1200				
Conditioning	-				10			
Carbon removal	15							
Conditioning	3		10.4	1500		300		
Conditioning	3						25	
Conditioning	1							50
Rougher flot.	4							
Conditioning	3						20	
Conditioning	1							50
Scavg. flot.	4							

Remarks: Same as for Test 92, except 10 L/t, 2% sol'n of surfactant 5753-11-1 was sprayed on the ore

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	20.8	24.04	97.1
Scavg. conc.	3.9	1.49	1.1
Tails	75.3	0.12	1.8
Head (calc.)	100.0	5.15	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine Dow's surfactants response to carbon adsorption technique

TEST NO: 124

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					Same as for Test 92,
Conditioning	1		9.2	1200					except 50 L/t, 2%
Conditioning	15				20				sol'n of surfactant
Carbon removal	-								5753-11-1 was sprayed
Conditioning	3		10.4	1500		300			on the ore
Conditioning	3						25		
Conditioning	1							50	
Rougher flot.	4								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	18.9	24.66	95.1
Scavg. conc.	3.6	3.57	2.6
Tails	77.5	0.14	2.3
Head (calc.)	100.0	4.90	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine G.A.P.'s surfactants response to carbon adsorption technique

TEST NO: 125

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					Same as for Test 92, except 10 L/t, 2% sol'n of surfactant BL-214 was sprayed on the ore
Conditioning	1		9.2	1200					
Conditioning	15				10				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		
Conditioning	1							50	
Rougher flot.	5								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	21.8	23.43	97.0
Scavg. conc.	2.4	2.65	1.2
Tails	75.8	0.13	1.8
Head (calc.)	100.0	5.27	100.0

SAMPLE: Opemiska copper ore

OBJECT OF TEST: Determine G.A.F.'s surfactants response to carbon adsorption technique

TEST NO: 128

Operation	Time min.	% Solids	pH	Rpm	Reagents - g/t Carbon kg/t	Lime	Xanthate 350	MIBC	Remarks
Grinding	18	65		75					Same as for Test 92, except 50 L/t, 2% sol'n of surfactant BL-214 was sprayed on the ore
Conditioning	1		9.2	1200					
Conditioning	15				20				
Carbon removal	-								
Conditioning	3		10.4	1500		300			
Conditioning	3						25		
Conditioning	1							50	
Rougher flot.	4								
Conditioning	3						20		
Conditioning	1							50	
Scavg. flot.	4								

Product	Wt %	Assay % Cu	% Dist. Cu
Rougher conc.	17.3	23.88	90.0
Scavg. conc.	2.3	12.88	6.5
Tails	80.4	0.20	3.5
Head (calc.)	100.0	4.59	
Rougher + scavg. conc.	19.6	22.59	96.5